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from

Eugene Herrin

and

Tom Goforth

Dallas Seismological Observatory
Southern Methodist University
Dallas, Texas 75275

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CRUSTAL STUDIES OF THE NEVADA TEST SITE:
INTERPRETATION OF SMU LINE E-3

by

Tom Goforth, John Ferguson
and
Eugene Herrin

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Southern Methodist University

July 1979

CRUSTAL STUDIES OF THE NEVADA TEST SITE

ABSTRACT

During January 1978 a seismic reflection survey was conducted at Yucca Flat on the Nevada Test Site. A total of 25 line miles was surveyed, including two east-west profiles perpendicular to the trend of the valley and one north-south profile parallel to the trend. Four Y-900 LF vibrators were used to generate signals. Because of the expected high attenuative characteristics of the dry alluvium in Yucca Flat, 4.5 Hz geophones and low-frequency sweeps were employed. A structural cross-section which is consistent with gravity and borehole data is presented for the southern portion of Yucca Flat.

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INTRODUCTION

The Problem

Although a few underground nuclear explosions have been conducted by the United States in places such as the Aleutian Islands, New Mexico and Mississippi, the great majority of the explosions has taken place on the Nevada Test Site (NTS). Thus, most of the reliable data which can be used to establish relationships between explosion yield and the amplitude of seismic waves radiated from the explosions must come from NTS. The test site, located in the Basin and Range Province of the United States, is in an area with high terrestrial heat flow, high crustal and upper mantle temperatures, a relatively thin crust and a moderate-to- high level of seismic activity. The existence of these rather anomalous conditions beneath NTS has led to considerable speculation as to their effect upon the relationship between explosion yield and seismic amplitudes, but no entirely acceptable conclusions have been reached.

The two types of seismic waves most likely to be recorded from underground explosions are the P-wave, which travels through the earth, and the Rayleigh wave which travels primarily in the earth's relatively thin outer crust. We can consider the factors which significantly influence the amplitudes of these waves radi-

ating from a given source in terms of the following categories:

(a) effects very close to the source; i.e., the seismic coupling factors,

(b) conditions existing along the propagation path; i.e., the propagation factors,

(c) conditions directly beneath the recording station; i.e., the station-amplitude factors.

By proper use of source-station combinations, data from explosions at NTS can be analysed so as essentially to eliminate station-amplitude factors in the study of the relationship between seismic amplitude and explosion yield.

The coupling factor (a) can be studied in terms of direct evidence obtained from bore-holes in the vicinity of the explosion site, and much work has already been done in determining the coupling factor for various rock types at NTS. Thus the propagation factor (b) remains to be considered. For P-waves, and to a lesser extent for Rayleigh waves, the propagation effects for most of the path from source to station can be predicted from the use of models employing parameters which represent "average" physical properties for the crust and mantle of the earth. However, variations in physical properties of rocks beneath the explosion point, but too deep to have been sampled by bore-holes, may lead to propagation effects which can not be explained using

"average" earth models.

In several areas of the Nevada Test Site, for example, Yucca Valley and Payute Mesa, systematic variations in the yield-seismic amplitude relationship have been observed which can not at this time be explained by variations in the coupling factor (a). It has been suggested by several scientists studying this problem that these variations result from systematic variations in the physical properties of the upper crust beneath the testing areas. No direct evidence concerning these properties can be obtained because the rocks involved have not been sampled by the drill. Remote sensing methods, of which the reflection seismic technique is by far the most reliable, were therefore suggested for the study of this problem. In this report, we outline a procedure for planning, carrying out and evaluating seismic reflection studies in the Yucca Flat area of the Nevada Test Site.

Advisory Committee

An advisory committee composed of the following members was established: Eugene Herrin and Tom Goforth, Southern Methodist University; Tom McEvilly, University of California at Berkeley; Alan Ryall and Ralph Alewine, DARPA; Fred Followill, Lawrence Livermore Laboratory; and Bill Best, AFOSR.

The committee participated in the general planning of the research program and concurred in the selection of a suitable sub-contractor to obtain and process the reflection data at NTS.

The committee also assisted in the selection of operational parameters for the survey such as geophone group spacings, length and frequency content of vibration sweeps, and other factors which had to be specifically tailored to the dry alluvial-fill environment of Yucca Flat. The committee, after meeting at NTS and studying available maps concerning locations of bomb craters, radiated areas, topographic relief, and access roads, selected the specific lines to be seismically surveyed.

Selection of the Sub-Contractor

Requests for bids for the seismic survey and subsequent data analysis were sent to Western Geophysical Company, Petty-Ray Geophysical Company, and Geophysical Services Incorporated. Western Geophysical and Petty-Ray responded with bids, and on the basis of total cost, the proven ability of the company to obtain deep reflections using vibrators as sources, the capability of providing a crew at NTS by January 1978, and the availability of 4.5 Hz geophones, Western was selected as the sub-contractor.

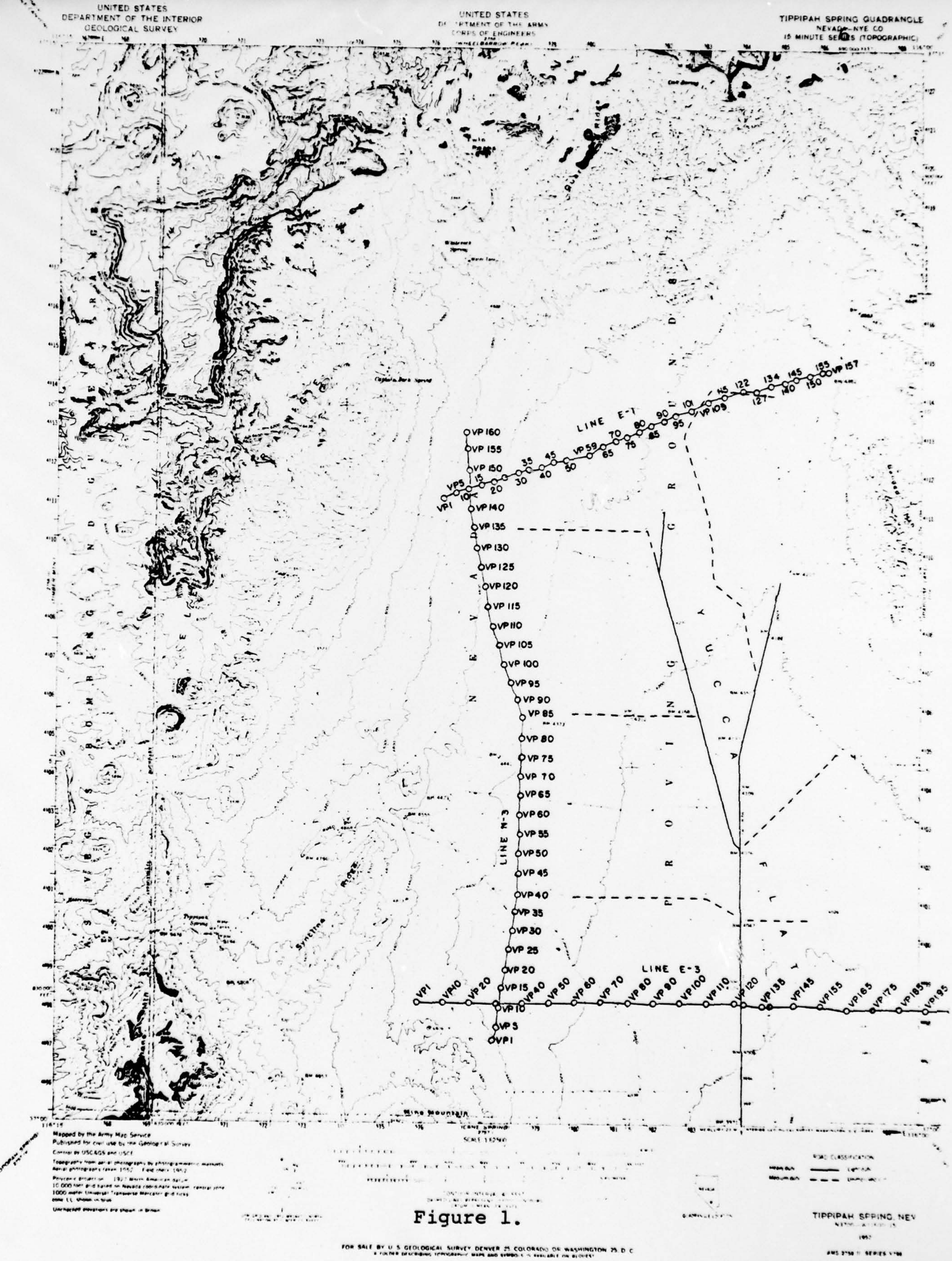
THE SEISMIC SURVEY

Initial Considerations

The objective of the seismic survey was to delineate the Yucca Flat geologic structure to the depth of the Mohorovicic discontinuity. Both the amount of funding available and the inaccessibility of many regions of Yucca Flat due to cratering and excessive radiation limited the total length of survey line to 25 miles. The layout of the resulting three survey lines is shown in figure 1. Line E-1 crosses the strike of the valley and is 6.5 miles (10.5 km) long. To the south, line E-3 also crosses the strike of the valley and is 8.5 miles (13.7 km) long. Line N-3 is approximately parallel to the strike of the valley and is 10.0 miles (16.1 km) long.

Field Operations

The survey was accomplished during the period January 6, 1978, to February 4, 1978. Four Y-900 LF vibrators were used to generate signals. Recording was accomplished by 48 groups of 4.5 Hz geophones with 36 geophones per group. The sampling interval was 4 milliseconds, and 24-fold coverage was obtained for all lines. The seismometer group and vibrator point intervals were 330 feet for line N-3 and 220 feet for lines E-1 and E-2. Thirty-



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TIPPIPAH SPRING QUADRANGLE
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Figure 1.

two sweeps were made at each vibration point. An 18-second sweep of 8 to 32 Hz was used on line N-3, while a 12-second sweep of 6 to 32 Hz was used on line E-1, and a 12-second sweep of 8 to 32 Hz on line E-3. The 4.5 Hz geophones and the extension of the sweeps to low frequencies were used because of the high attenuative characteristics of the dry alluvium through which the waves had to penetrate. The alluvial cover under line N-3, which extends along the edge of the valley, is relatively thin, and the seismometer group spacing was extended to 330 feet on that line in the hope of obtaining a reflection from the Mohorovicic discontinuity.

Location of vibration and recording points was accomplished by a theodolite survey with ties at line intersections to U.S.G.S. Bench Marks. Elevation ties were maintained to within ± 3 feet and horizontal ties to within ± 25 feet.

A 48-channel LRS COBA® recording system was used throughout the survey. This system employs the COBA® I single floating point amplifier which is time shared by all data channels and is capable of adapting to the full dynamic range of the input signal during any sample. The COBA® II sub-system adds a mini-computer peripheral to the COBA® I. Under software control, it provides vertical summing, noise suppression, and instrument test diagnostics. A 24-channel correlator was employed to provide monitoring of data quality during field operations, but actual correlation

of the vertically summed field data was done at the Denver processing center. Vertically summed field data were recorded on ½-inch magnetic tape at 1600 bits/inch in a standard computer compatible SEG "C" format. The geophones used were 4.5 Hz Mark Products Model L-15A.

Data Processing

The seismic data were processed exclusively by Western Geophysical Company at their Denver, Colorado, office. Details of the work are contained in the Appendix. The processing steps are briefly outlined as follows.

(1) The VIBROSEIS® sweep signals were cross correlated with the seismic recordings to recover the zero phase records.

(2) Static corrections for elevation were performed to a datum of 4300 feet elevation with a velocity of 6000 feet/sec. High amplitude initial arrivals were muted at this point.

(3) Velocity scan analysis was performed with the VELAN® program on the common depth point families. This technique consists of applying a range of normal moveout correction velocities and measuring correlations at each discrete velocity. High correlations are associated with velocities close to

the true RMS velocity at a given travel time. A velocity function was constructed from this analysis for use in the stacking procedure.

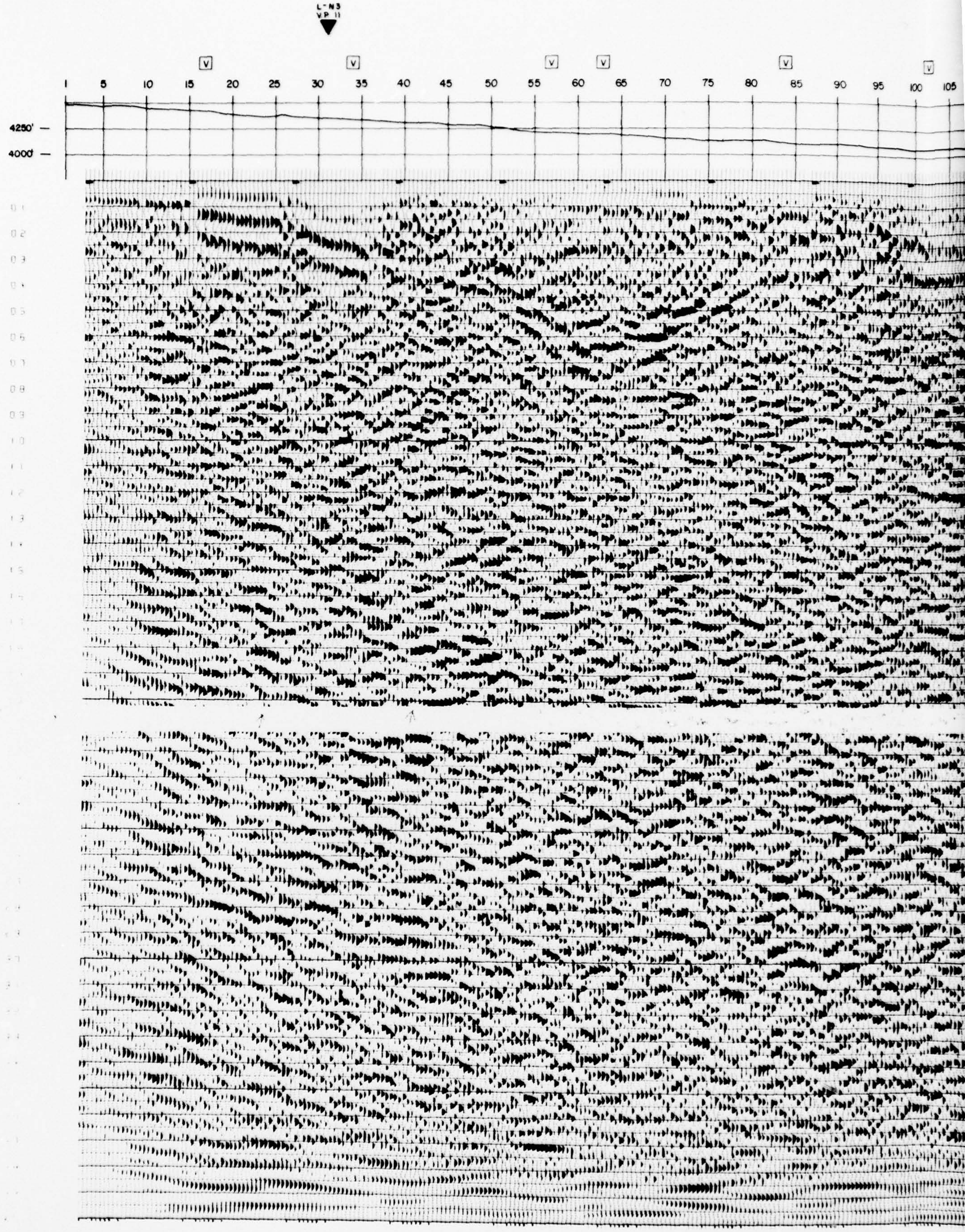
(4) A common depth point (CDP) stacked section was compiled.

(5) Wave equation migration was applied to the CDP stack to correct for geometric effects and recover the subsurface structure.

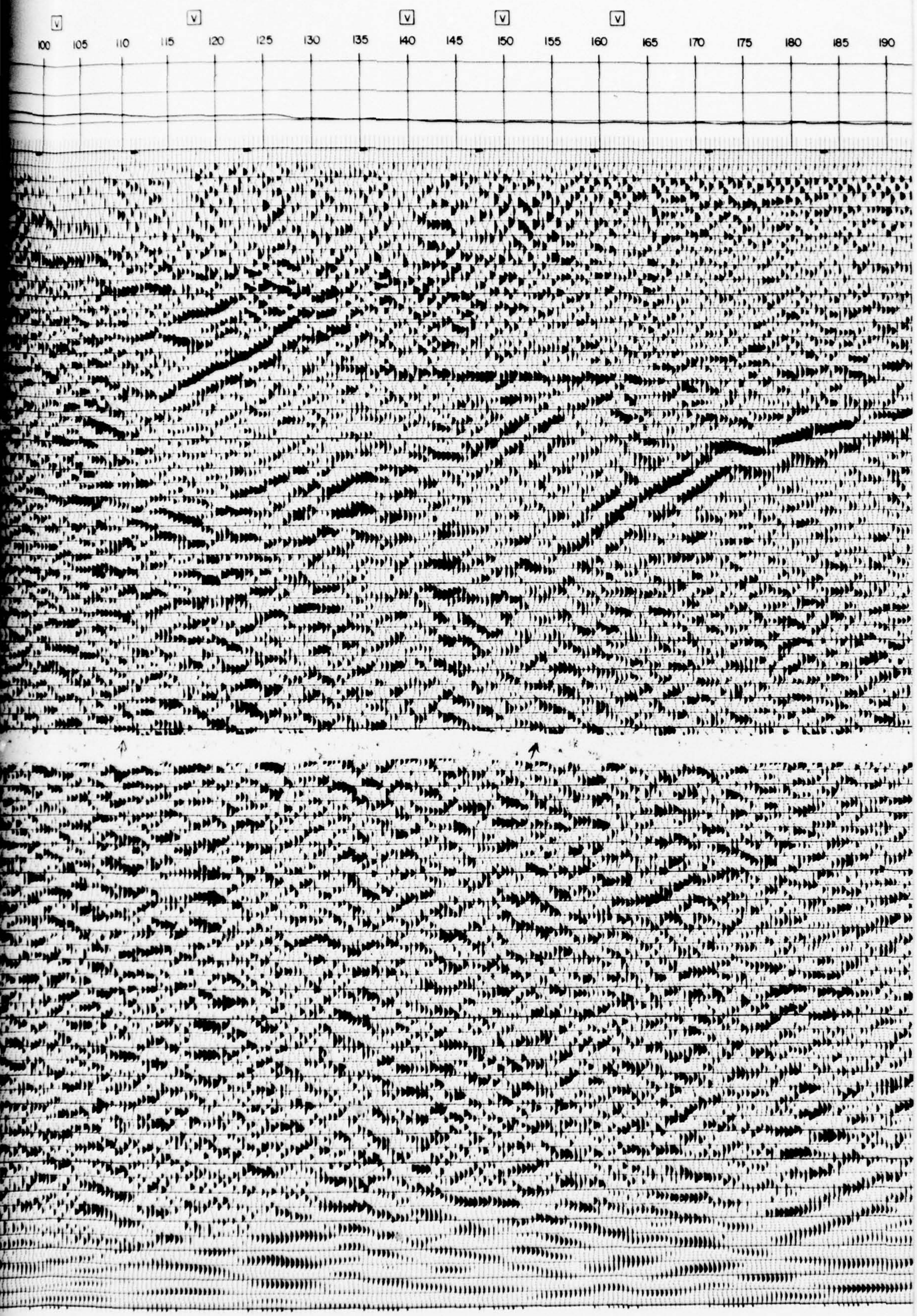
Both the velocity scan and CDP techniques imply the existence of structure which is approximately horizontally layered. Departures from this type of structure cause overestimates of the velocity and a degradation of the stacked and migrated section. Both effects are observed in the E-3 section due to the extreme lateral velocity variation caused by faulting of profoundly different velocity layers. A remedy for this problem is migration prior to stacking. This procedure is highly recommended for the ensuing studies in order to explain the occurrence of VELAN® velocities which are 25% too high in comparison to known velocity structure.

Interpretation

The migrated CDP section compiled for line E-3 is shown in figure 2. The important reflecting events have been identified, and the resulting interpreted time section is shown in figure 3.



L-N3
VP 11
V
V
V
V
V
V
1 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105
4250'
4000'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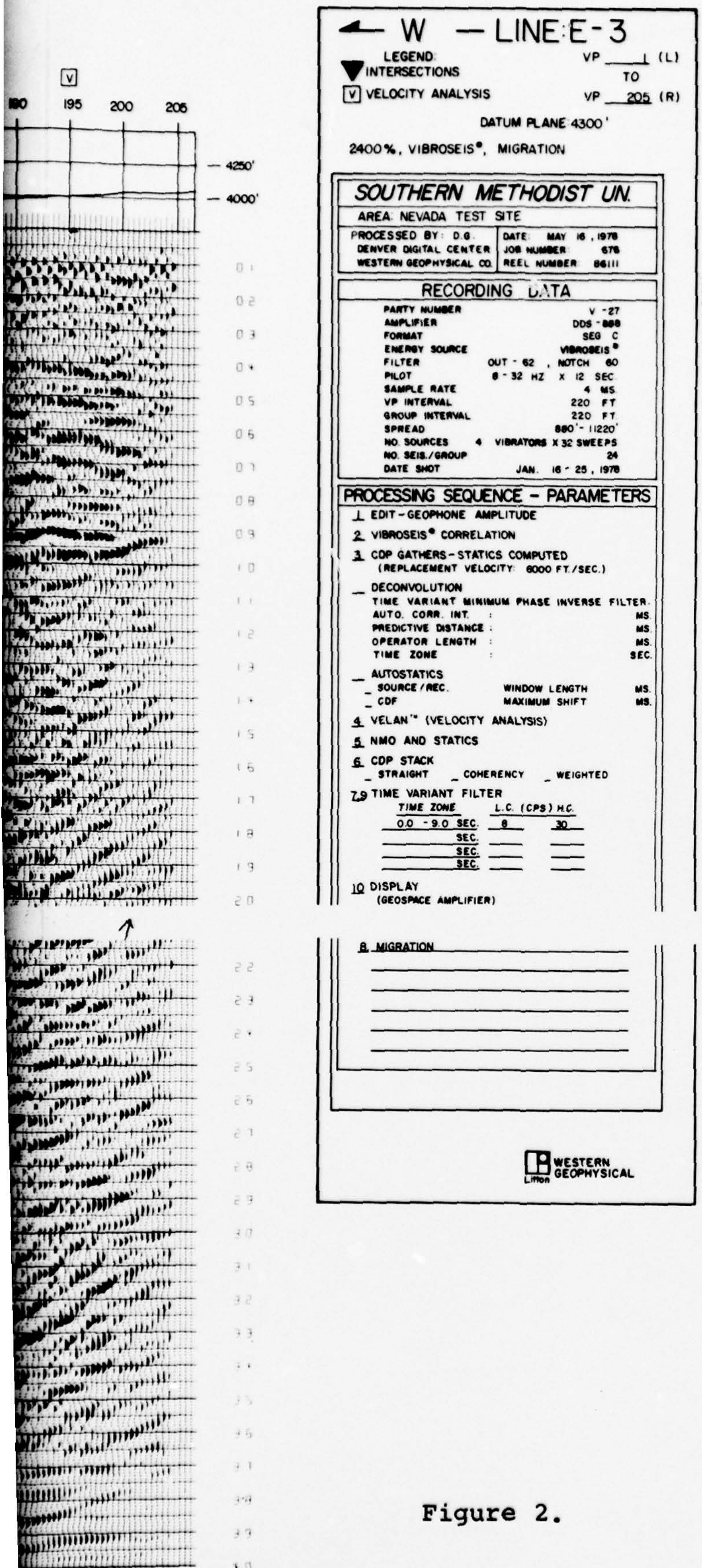

Figure 2.

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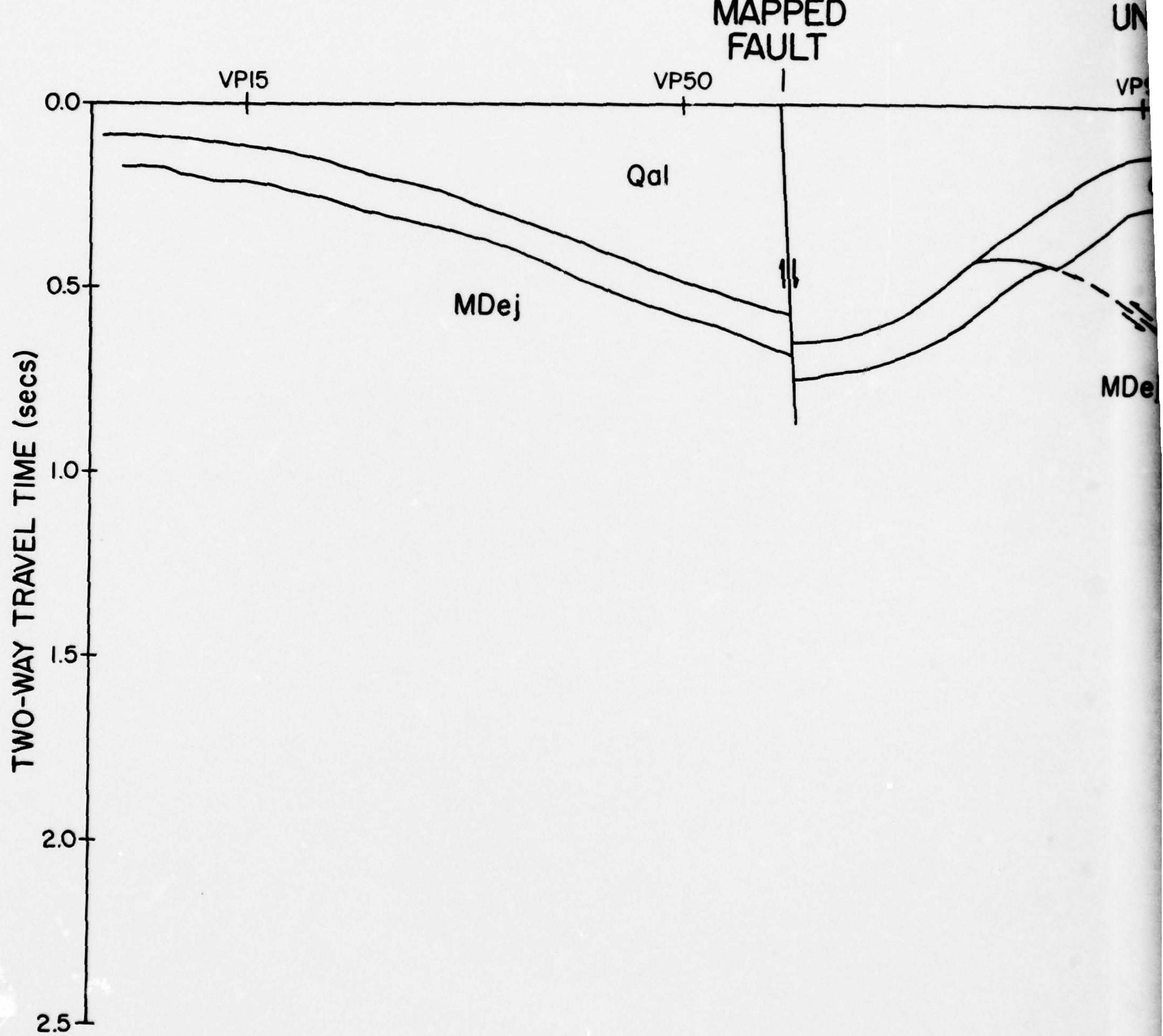
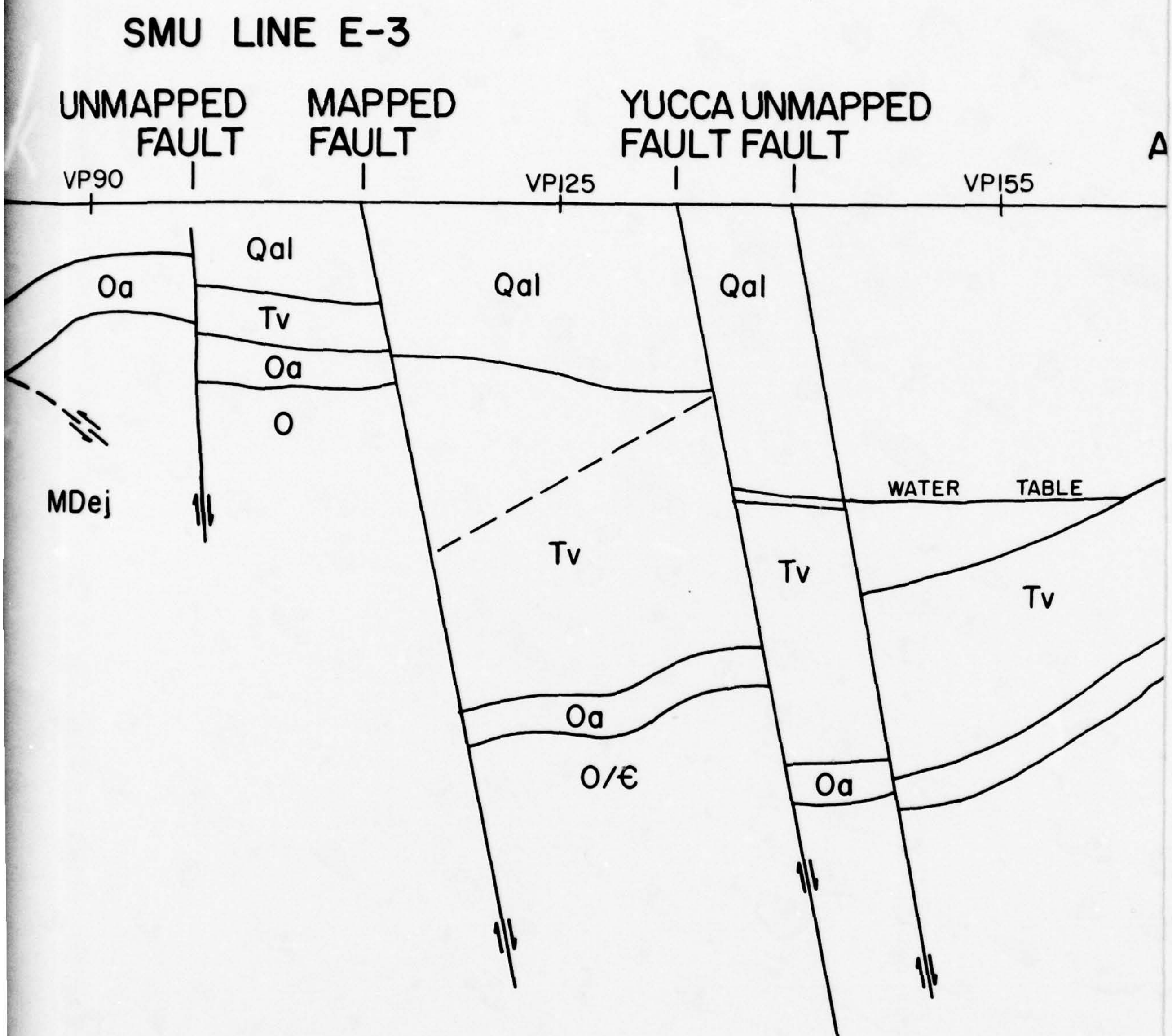


MAPPED
FAULT
UN
VP15
VP50
VP
0.0
0.5
1.0
1.5
2.0
2.5
TWO-WAY TRAVEL TIME (secs)
Qal
MDej
MDej


SMU LINE E-3
UNMAPPED FAULT
MAPPED FAULT
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UNMAPPED FAULT
A
VP90
VP125
VP155
Qal
Oa
Tv
O
MDej
WATER TABLE
O/€

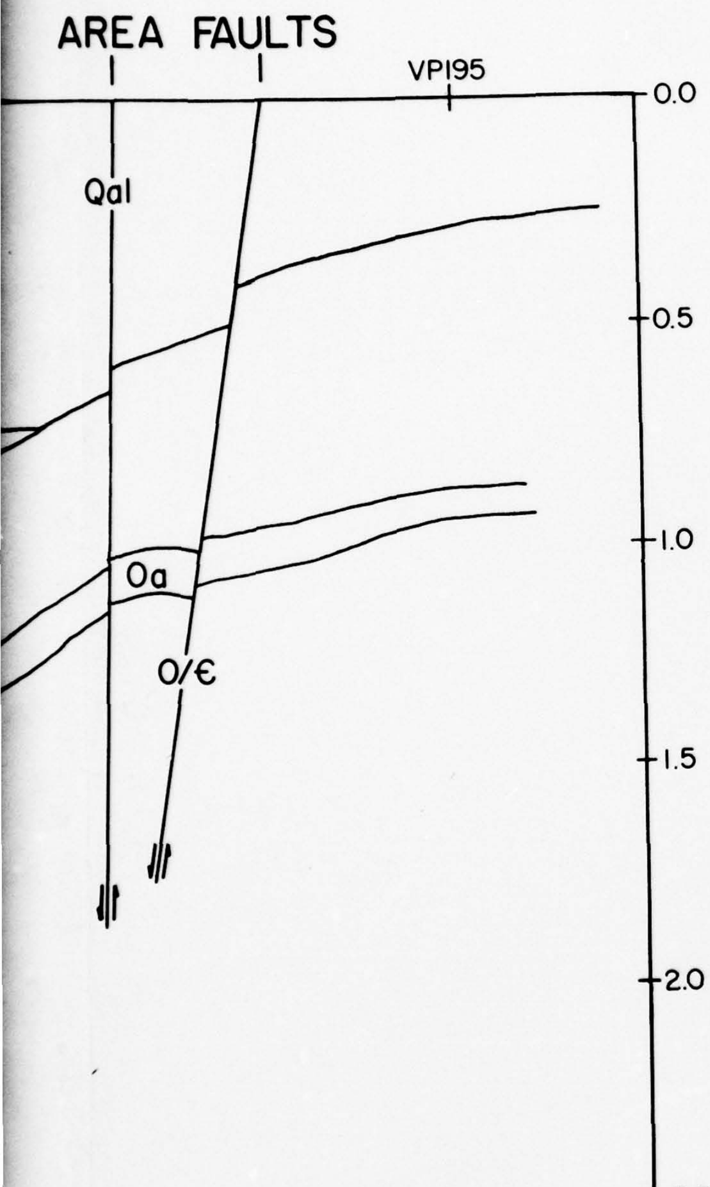


Figure 3.

The most prominent reflector is the post-Paleozoic unconformity. Paleozoic sediments are marked Oa over most of the eastern end of the profile and are believed to coincide with the Ordovician Antelope Valley limestone in the CP thrust sheet. The thrust itself is shown near VP 70 where there is some evidence in the section that lateral change is occurring in the reflecting unit. The Mississippian-Devonian Eleana formation is believed to underlie the thrust and comprise the top of the section to the west. The direction of motion shown in figure 3 for the CP thrust is taken from the geologic map of the Yucca Lake Quadrangle GQ-1327 published in 1976. This motion is contrary to previous publications.

The contact between Quaternary alluvium and Tertiary volcanic rocks is prominent only below the water table, which is itself an important reflector between VP 130 and VP 160. Although the contact is shown above the water table, the reflector is poorly defined. Given a reasonable velocity function, the identified horizon agrees with borehole control. No volcanics occur to the west of VP 90 in this area.

The normal faults shown on this section are well identified. Some agree with mapped surface faults, and some do not. The very important fault near VP 110 is shown on maps of Yucca Flat but is not named. It may be a rejuvenation of the Tippinip Fault which trends through this area.

As previously discussed, the velocity scan data is questionable. Borehole velocities range from 3000 ft/sec to 6000 ft/sec in the alluvium and 6000 ft/sec to 10000 ft/sec in the volcanics (mostly air fall tuff). The Paleozoic basement velocities are greater than 10000 ft/sec. The average velocity for the entire Quaternary-Tertiary section is around 6000 ft/sec. This gives a depth of around 4200 ft for the deepest part of the basin. The agreement with the gravity model to be discussed later is quite good. Both seismic and gravity data can be brought into agreement by reasonable adjustments to the velocity function and/or the regional gravity anomaly. It should be noted that well log data indicate a constant (with depth) density function and an increasing (with depth) velocity function. This relationship does not follow the laws normally expected for clastic sediments.

No definite reflection from the Mohorovicic discontinuity could be identified. A series of weak, discontinuous reflections were observed on line N-3 between vibration points (VP) 120 and 160 at a two way travel time of 10.5 seconds. However, line E-1 which ties to line N-3 at VP 145 showed no such line-up.

ANALYSIS OF THE GRAVITY DATA

Description of Data

The United States Geological Survey has observed some 8500 gravity stations in the Yucca Flat vicinity. These data are open file and have been obtained by us to supplement the seismic observations. The data have been collected over a twenty year period with instruments of varying quality, but generally with good elevation and latitude control by survey. The data are on magnetic tape with location to 0.01 minute, elevation to 0.1 foot and terrain corrected Bouguer anomaly to 0.01 milligal.

Reduction of Data

The contoured anomaly values demonstrate that the structure on the eastern end (VP 100 and greater) of SMU line E-3, is virtually two dimensional, with a north-south trend. The western end shows some distinct departures from a two dimensional structure, but it is nevertheless reasonable to perform an interpretation of a profile along E-3 under that assumption.

Rather than manually derive a profile from a hand contoured map, it was decided to use a numerical procedure on the digital data. First a selection of all 360 stations within several thousand feet north or south of N 830000 (the latitude of line E-3)

was made from the tape. These data were further reduced to the 96 stations closest to the line such that the north-south projections onto the line were no closer than 200 feet apart. A smoothed cubic spline was fit to these 96 projected data. The smoothing was based on the subjective measure that no anomaly be defined by a single data point. A smoothed spline function need not, and generally will not, pass through the knots. The selected function had an RMS error of 0.23 mgal. Thirty two evenly spaced (1650 feet interval) samples were computed from the spline function for further analysis.

The regional anomaly was approximated by a simple linear gradient passing through the high gravity anomalies over the Eleana Range and Paiute Ridge, where Paleozoic rocks outcrop. This trend was removed from the profile data points.

<u>Analysis of Geophysical Logs</u>

Stratigraphic and geophysical log summaries were obtained from Los Alamos Scientific Laboratory and were used to constrain the physical properties and geologic horizons in the Yucca Flat basin for this study. The number and types of logs used are shown in Table 1.

Table 1.

Summary of Geophysical and Stratigraphic Logs Used in the Nevada Test Site Crustal Study

	Type of Log				
Total Number	Stratigraphic	Density	Sonic	Areas	Lowest Unit
17	17	12	7	3	Quaternary
33	33	17	13	3,4,7	Tertiary
42	17	7	4	1,2,3, 4,6,7, 8,9,10, 12,15	Paleozoic

The Paleozoic tags without stratigraphic logs are from Healey (1966 and 1968). The LASL summary consists of interval density and velocity information for each unit identified in the borehole as well as other geophysical information on occasion.

The following holes were used to estimate the average density contrast of the basin; U3JK, U3JL, U3KB, U3KD, U3KP, UE3FD1, U4AB, UE4AD, U7AB, U7AH, U7AJS, U7AP, U7AW, U7AY, and UE7NS. The densities were averaged over depths for the Quaternary alluvium (QAL) alone and also for the combined QAL and Tertiary volcanic section (Tv). Very few data are available in the Paleozoic (Pz).

A statistical summary of these holes is in the following table (units are gm/cm^3):

Table 2.

Densities Obtained from Borehole Logs

Unit	Mean	Standard Deviation	Median
Qal	1.75	0.15	1.815
Tv	1.71	0.14	1.755
Qal & Tv	1.75	0.10	1.79
Pz			~ 2.5

The density of the Tv actually appears to be less than that of the Qal, but the difference is not significant. These values may also be about 0.1 gm/cm^3 too low due to borehole effects on the density log. If so, they could be corrected to agree with the values in Healey (1962), but the relative contrast remains at 0.7 gm/cm^3 as has been standard at NTS for years. The Qal and Tv are not differentiated on the basis of density. Higher density welded tuffs seem to be a very minor component of the section. Also, water saturation has little effect on the density.

Only a few general remarks can be made on the velocity log data. The formation velocities are 3000 to 6000 ft/sec in Qal, 6000 to 10000 ft/sec in Tv and over 12000 ft/sec in Pz. The velocity function increases almost linearly with depth until about 2000 ft, and then it becomes nearly constant at about 9000 ft/sec. There seem to be considerable local departures from this

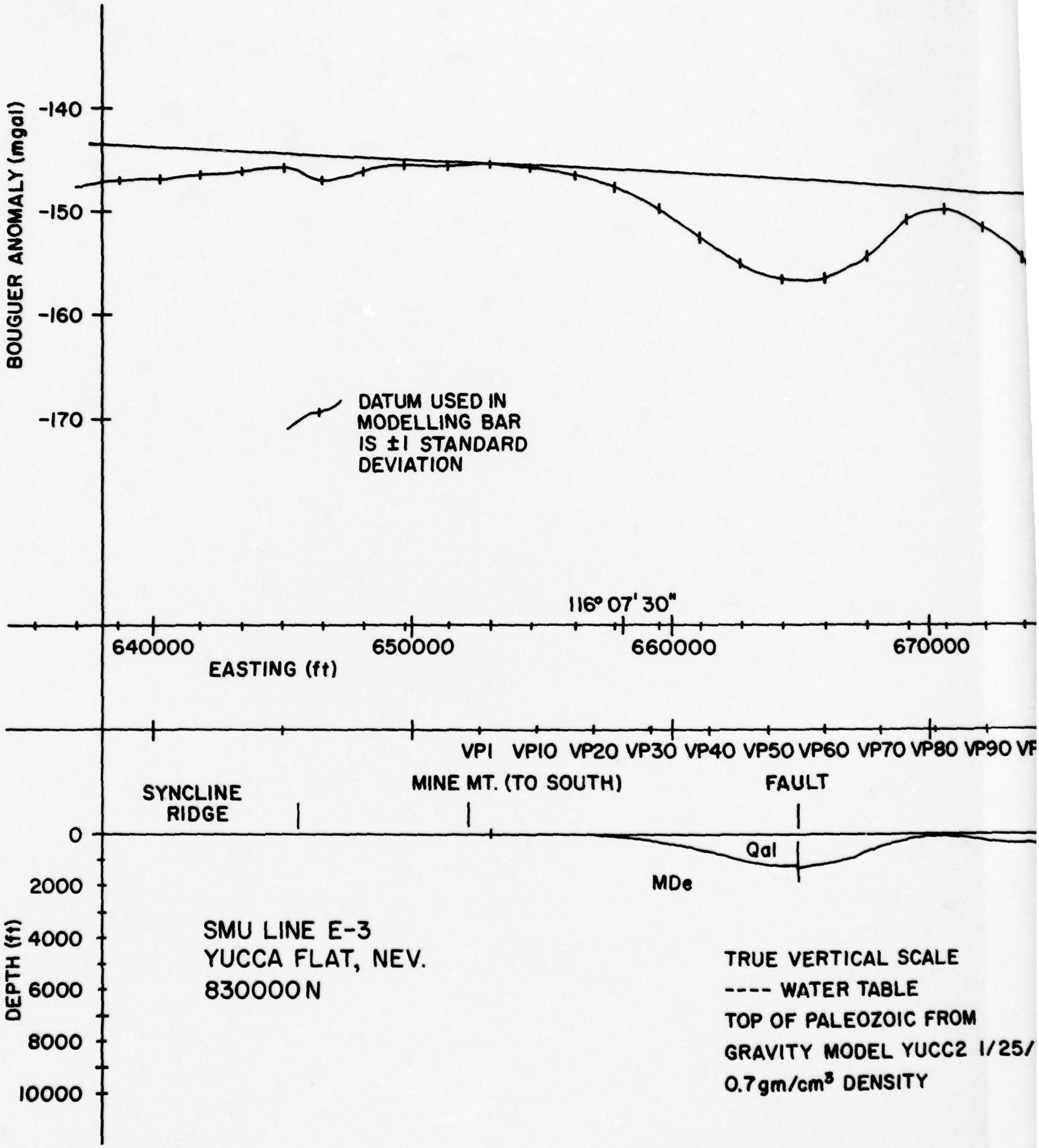
behavior both vertically and horizontally in the Yucca Flat area as would be expected in a volcanic basin.

Interpretation

Due to the simple shape of the gravity anomaly and the uniformity of the borehole density measurements, the Yucca Flat basin can be modelled by a low density layer of variable thickness over a half space. Only a single density contrast of $-0.7\ gm/cm^3$ is required to explain the anomaly. The technique used to interpret these data is a formal inversion of the integral equation defining the gravitational acceleration for this type of mass distribution.

This process is equivalent to a downward continuation of the gravity data. A smoothness criterion was forced onto the model to control the instability inherent in this process. The details of the mathematical method will be the subject of a future report. The process maps the gravity anomaly into the basement depth to produce a smooth model with a theoretical anomaly in agreement with the observed.

The cross section shown in figure 4 is a composite of information from gravity, seismic and borehole data. In general it is correct, but the Paleozoic contact depth is only approximate due to uncertainties in the regional gravity anomaly and the seismic velocity. The shape of the surface and relative locations are correct, however.



BOUGUER ANOMALY (mgal)
-140
-150
-160
-170
DATUM USED IN MODELLING BAR IS ±1 STANDARD DEVIATION
116° 07' 30"
640000
650000
660000
670000
EASTING (ft)
VP1 VP10 VP20 VP30 VP40 VP50 VP60 VP70 VP80 VP90
SYNCLINE RIDGE
MINE MT. (TO SOUTH)
FAULT
0
2000
4000
6000
8000
10000
DEPTH (ft)
Qal
MDe
SMU LINE E-3
YUCCA FLAT, NEV.
830000 N
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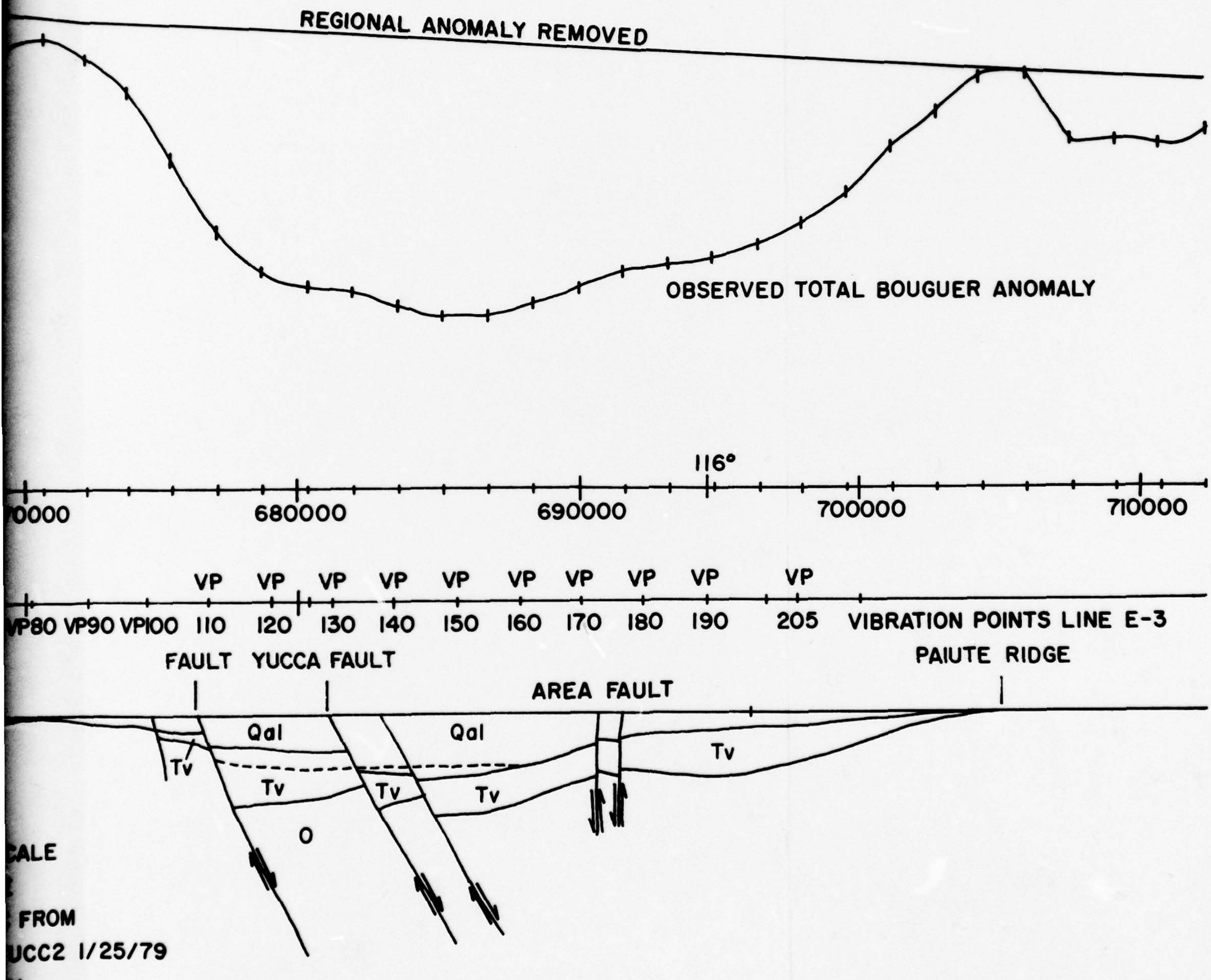
---- WATER TABLE
TOP OF PALEOZOIC FROM
GRAVITY MODEL YUCC2 1/25/
0.7gm/cm³ DENSITY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VP80 VP90 VP100 110
120
130
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VIBRATION POINTS LINE E-3
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Figure 4.

The depth of the Paleozoic basement is controlled by the gravity interpretation assuming a -0.7 gm/cm^3 density contrast and allowing an error in the gravity data of 0.5 mgal at all 32 observations. The basement surface was evaluated at 34 points. The Tertiary contact was controlled by seismic data and by boreholes U3DG, U3DQ, U3DX, U3EK, U3FD, UE3FD1, U3GE, U3GK, UE3HD1 and UE3HZ1.

The faults were located from the seismic section. The larger faults coincided with steep gradients in the gravity controlled basement surface, which is clear evidence of faulting.

The maximum depth of the basement, near the Yucca Fault, is slightly less than 4000 feet. If a proper regional anomaly were used, the depth would increase by several hundred feet. The basin is quite shallow on the west where the two dimensional assumption starts to break down. The presence of an emerging structure to the south causes the basement to appear to be aout 30 per cent more shallow than it should be.

The important geological interpretation to be made here is the significance of the unnamed fault near VP 110. This may be a late rejuvenation of the Tippinip Fault as a normal fault. In this part of the valley, it is the main bounding fault of the graben. The basin west of the fault is mainly a pediment, and all faults to the east are subordinate to this main fault. The variable unit thicknesses across the faults indicate that the faulting was contemporaneous with the Tertiary volcanic deposition.

CONCLUSIONS AND FUTURE STUDIES

The seismic and gravity interpretation for SMU Line E-3 clearly shows that the southern end of Yucca Valley between Syncline Ridge on the west and Paiute Ridge on the east is markedly asymmetrical in sub-surface structure. The fault which crops out between VP 100 and VP 110 has not been mentioned in the literature; however, the E-3 section shows it to be significantly larger in throw than the well-known Yucca fault. Together these two faults have over 3000 feet of vertical displacement and form the western boundary of the deep part of the Yucca Valley basin.

Preliminary analysis of SMU Line E-1 across Yucca Valley to the north shows that the sub-surface structure changes greatly in detail but that the asymmetrical pattern seen in E-3 persists. We believe that to a first approximation line E-3 indicates the general structural pattern present beneath Yucca Valley.

All of the underground explosions used to study yield-magnitude relationships for Yucca Valley took place at various distances to the east of the large fault but were located both east and west of Yucca fault. Because of the large mismatch in acoustic impedance between the Tertiary volcanics and the Paleozoic rocks, the large fault beneath VP 110 must exert considerable influence on the radiation pattern of seismic waves from the underground

explosions.

Studies are now underway to complete the interpretation of the other two seismic lines and collect additional borehole information. These data will be used as constraints for inverting the gravity data to obtain a three dimensional structural model for Yucca Valley. After the model is completed we plan to investigate the effect of the structure on the propagation of seismic waves from sources in the valley.

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APPENDIX

VIBROSEIS® SURVEY

of the

NEVADA TEST SITE

for

SOUTHERN METHODIST UNIVERSITY

by

WESTERN GEOPHYSICAL COMPANY OF AMERICA

Party V-27

PARTY MANAGER	SUPERVISOR
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JANUARY 6, 1978 through FEBRUARY 4, 1978

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I. INTRODUCTION

This survey was undertaken for the Institute for the Study of Earth and Man, Geophysical Laboratory, Southern Methodist University on January 6, 1978 and continued through February 4, 1978, for the purpose of gaining subsurface seismograph information of the structure of the earth's crust at three traverses on the Atomic Energy Commission's Nevada Test Site in Nye County, near Mercury, Nevada.

The survey was designed to delineate the entire geologic section to a depth of the mohorovic discontinuity, through new seismic techniques and equipment, to aid in nuclear detection studies.

II. LOCATION and CULTURE

Three lines were surveyed in the Yucca Flats Area of the Nevada Test Site. The crew was based at the NTS facility at Mercury, Nevada. The terrain is a relatively smooth area within the Yucca Flats, and the seismic traverses lay alongside existing roads and or trails.

III. FIELD OPERATIONS

A. PERMITTING

Dr. Eugene Herrin and Dr. Thomas Goforth, SMU technical represenatives, designated in the contract,

furnished specifications for the survey, obtained permits from all agencies, and advised on the technical aspects of the survey.

B. SURVEYING

Horizontal and vertical ties were made with a theodolite, trough surveys to U. S. Bench Marks and corners, and with ties at line intersections. Elevation ties were maintained to within plus or minus three feet, and horizontal ties to within plus or minus twenty five feet, which are standards for seismograph surveys.

C. RECORDING

1. PARAMETERS

Recording	24 fold CDP
Sample rate	4 miliseconds
Channels	48
Group interval	330', line N-3 220", lines E-1,& E-3
Vibrator Point interval	330', line N-3 220', lines E-1,& E-3
Spread	0'-990'-16,500', line N-3 0'-880'-11,220', line E-1&E-3
Geophones per group	36
No. Sweeps/VP	32
Length of sweep	18 seconds on line N-3 12 seconds, line E-1 & E-3
Listening time	12 seconds, line N-3 12 seconds, line E-1 8 seconds, line E-3
Type of sweep	8-32 hz. lines N-3 & E-3 6-32 hz. line E-1
Recording filter	out- 62 hz.

C. RECORDING

2. INSTRUMENTATION

A forty eight-channel LRS COBA® recording system was used throughout the survey. The system employs the COBA® I capability of a single floating point amplifier, time shared by all data channels, capable of adapting to the full dynamic range of the input signal during any sample and guaranteeing that all channels bridle perfectly.

The COBA® II system adds a medium size mini-computer peripheral to the COBA® I system, which under software control, provides vertical summing, user selected noise blocks, diversity summing, and instrument test diagnostics.

A twenty four channel LRS correlator, peripheral to COBA® I and COBA® II systems was employed to provide monitoring of data quality during field operations, but actual correlation of the vertically summed field data was done in the processing center.

Vertically summed field data were recorded on ½" magnetic tape at 1600 B P I phase encoded standard computer compatible SEG "C" format.

One hundred groups of CDP cables with maximum group spacing of 330 feet were used with seventy two groups of 36 each, Mark Products Model L-15A, 4 ½ hz geophones.

IV. EQUIPMENT

One (1)	Recording truck, Ford f-600, 4 x4
Four (4)	Y-900LF vibrators with Pelton Advance I electronics and base plate pads, Vibrators are mounted on I. H. M-5050 6 x 6 trucks.
One (1)	Vibrator service unit
One (1)	Party Manager's vehicle
One (1)	Survey pickup
One (1)	Permitman's vehicle
Three (3)	Cable trucks
-	Office equipment for field office.

V. DATA PROCESSING

The processing of field data from this project was done in Western's Digital Center in Denver, Colorado, under the direction of Jimmie Jarrell and Don Gardner, who are supplying the processing report for this project.

OPERATIONAL STATISTICS

PROJECT TERM	January 6 through February 4, 1978
CALENDAR DAYS	30.0
OPERATING DAYS	23.7
TOTAL MILES SURVEYED	25.0
AVERAGE MILES PER OPERATING DAY	1.06
AVERAGE VIBRATOR POINTS RECORDED DAILY	22.03

LINES SURVEYED

LINE NO.	VPs	MILES
N-3	172	10.0
E-1	157	6.5
E-3	193	8.0
TOTALS	522	25.0

S.M.U.

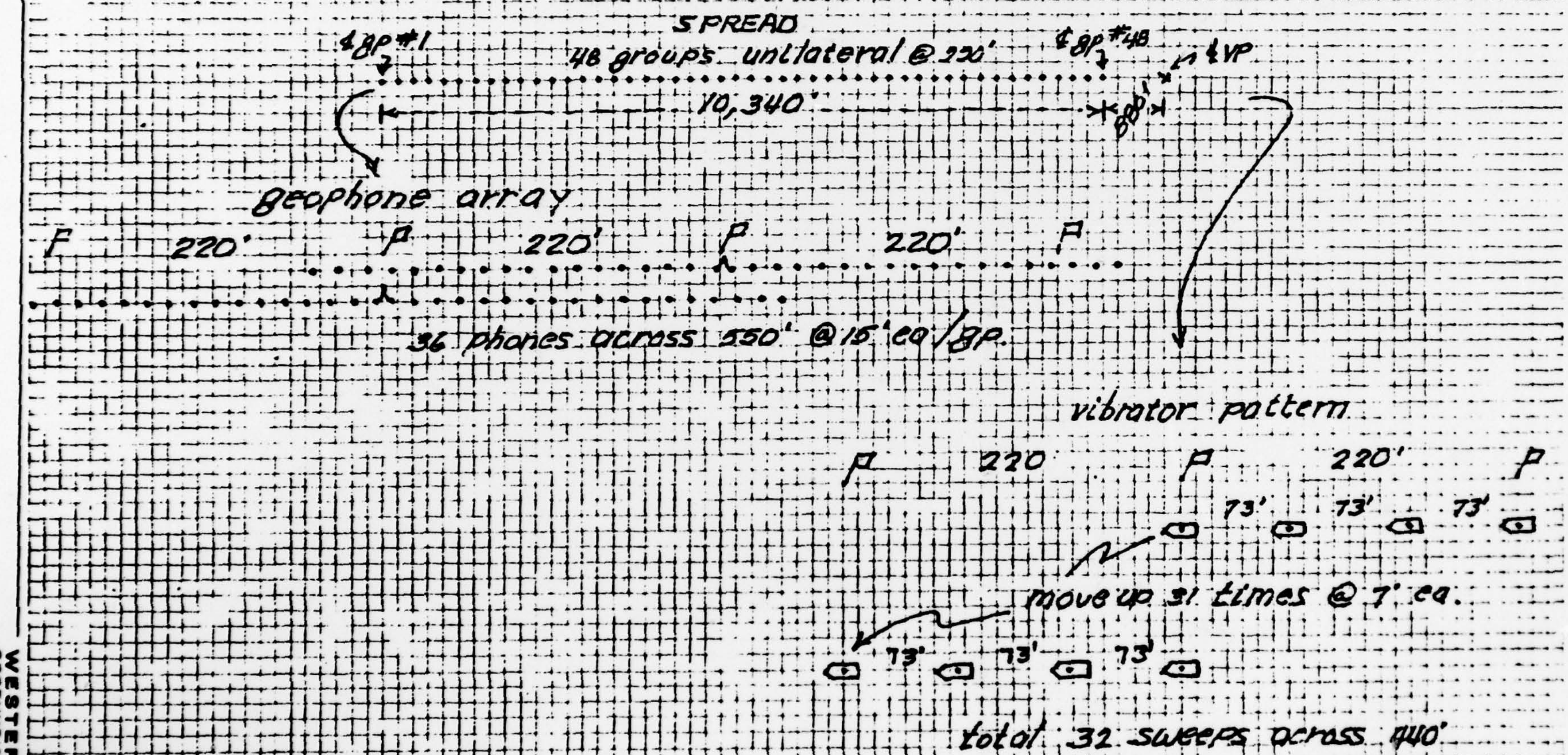
REFLECTION SPREAD

and

VIBRATOR PATTERN

for

LINE E-1



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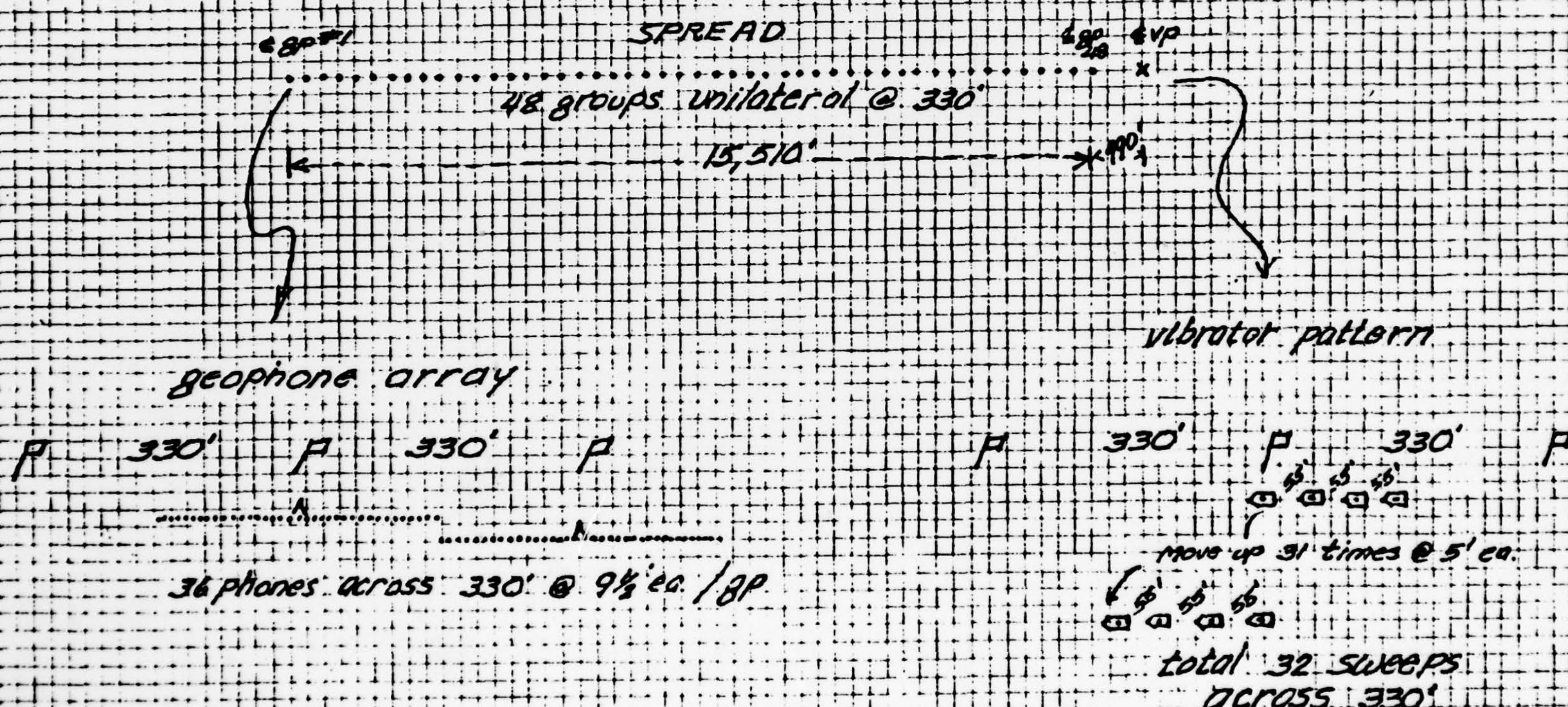
REFLECTION SPREAD
and
VIBRATOR PATTERN
for
LINE N-3



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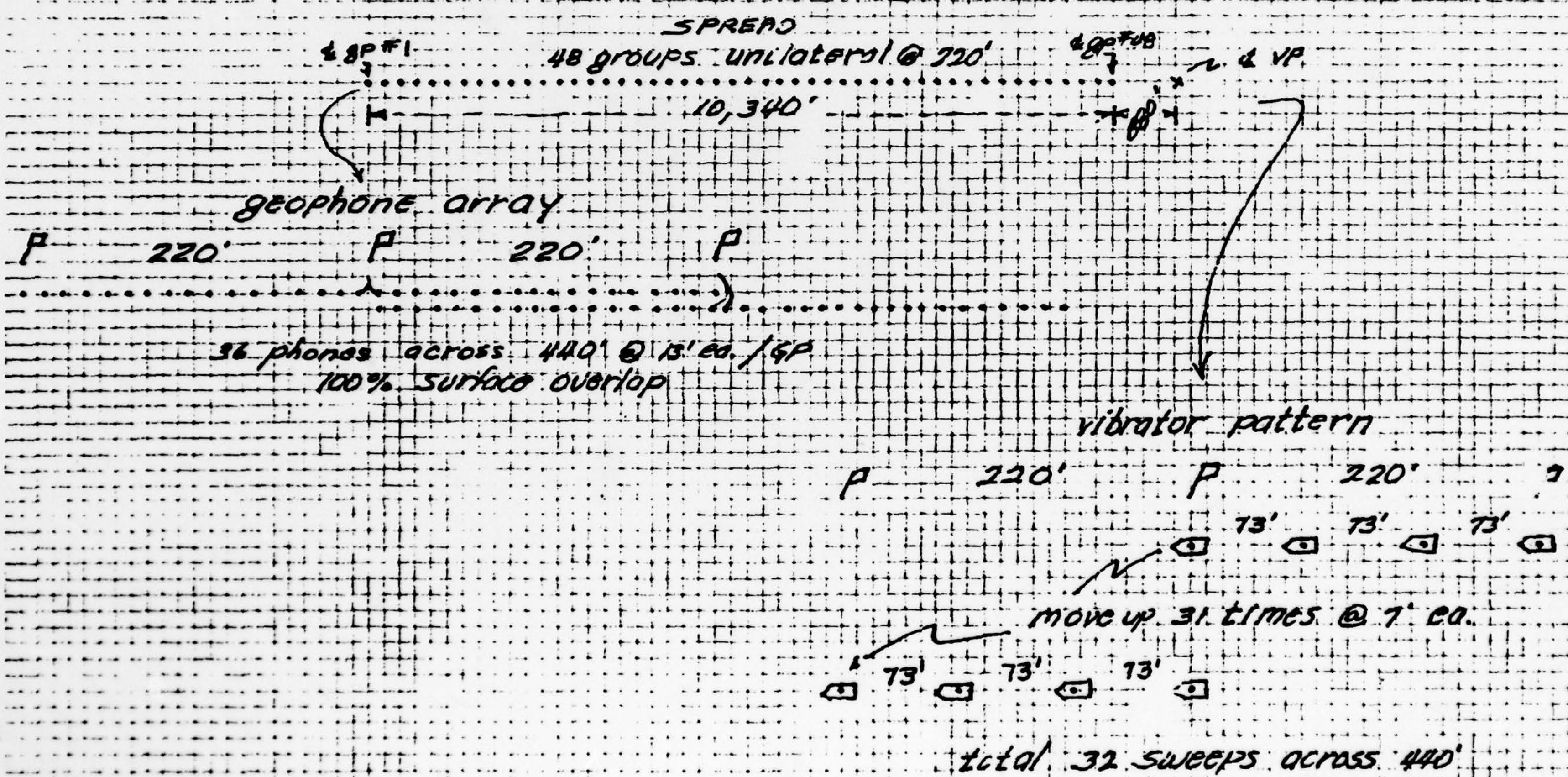
S.M.U.

REFLECTION SPREAD and VIBRATOR PATTERN for LINE E-3



PROCESSING DESCRIPTION

NEVADA TEST SITE

WESTERN GEOPHYSICAL DENVER DIGITAL CENTER

FEBRUARY, 1978 - MARCH, 1978

SOUTHERN METHODIST UNIVERSITY

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PROCESSING INTRODUCTION

The digital processing of data from the Nevada Test Site was performed in the Denver Digital Center between February and March, 1978.

The data was gathered using the VIBROSEIS® System and Litton Systems Model 888 COBA® 48 trace recording system. See the enclosed operations report.

A brief description of the processing sequence used on the data follows in the order in which they were applied.

SEGC EDIT

This program accepts as input full word floating point, SEG C formatted data. The outputs created were demultiplexed Western Code 4 format with 32 bit floating point, geophone amplitude restored data traces. A code 4 format is enclosed at the end of this report.

The printout lists the processing parameters as well as a listing of the field record lengths and file numbers.

Quality control plots were made of each VIBROSEIS® sweep and checked for proper frequency content and consistent start times.

VIBROSEIS® CORRELATION

In the VIBROSEIS® method, a mechanically vibrating base plate radiates into the earth a dispersed, nearly sinusoidal seismic signal of continuously varying frequency. The base plate is driven by a "pilot sweep signal" or "sweep" that is generated electronically either within the recording truck or at the vibrator. The central step in processing vibratory-source data involves cross correlation of the recorded seismic traces as they might look if the base plate radiated a short pulse instead of the long duration senusoidal vibrations. In this case, the sweep frequencies for the data were 8-32 and 6-32 Hz.

This cross correlation approach is an example of "matched filtering" --- a technique used in electrical engineering to detect a signal in the presence of noise when the form of the signal is known a priori, (Anstey, 1964). The fundamental principle involved is that the long duration (18 sec. and 12 sec.) sweeps will correlate poorly with all recorded wave-forms such as random noise and traffic noise that are not source-generated; however, correlations will tend to peak at the arrival times of waves that emanated from the source (Crawford, Doty and Lee, 1960). The resulting short pulses in the correlograms resemble the auto-correlation of the pilot sweep modified by the response of the vibrator-earth system.

The process of cross correlating a sweep and a data trace can be viewed as "partial deconvolution." Suppose that the oscillating sweep signal represents the response of some filter to a unit impulse (spike) input. A general definition of the deconvolution process is that it is a filtering operation that is designed to compensate a data trace for some effects of previous filtering. The correlation operation compresses the dispersed VIBROSEIS® wave train into a pulse by compensating

for the phase characteristics of the source. It is only partial deconvolution because frequency-dependent amplitude effects are not compensated.

Pilot Sweep Signal

Ideal matched filtering would be achieved by crosscorrelating with a replica of the radiated signal. However, the recorded pilot sweep signal is not truly the source waveform that is introduced into the earth. The electronic pilot signal shape if modified by the mechanical response of the vibrator and is further modified because of imperfect coupling between the vibrator and the earth.

The only recorded estimate of the source function available is usually the electronic pilot signal generated in the recording truck and saved on trace 1 of the edit tapes. The vibrators used a pilot signal generated at the vibrator but triggered from the recording truck.

For the newer VIBROSEIS systems the sweep is constant in both amplitude and phase for all vibrator points (VP's). Occasionally, if any filter settings are inadvertently changed from one day to another, the sweep may change (perhaps be delayed, distorted, or attenuated). In this program, the analyst has the choice of (1) using the particular sweep trace recorded at each VP for correlations, or (2) using a single sweep trace (the first one on the input tape) for all correlations. This common-sweep option may be preferred for RAP processing when the only known variations amongst actual sweeps involve RMS amplitudes. However, to properly compensate for other distortions or delays, it is best to use the pilot signals recorded at the various VP's.

Each record was displayed after correlation and inspected to determine the necessary trace editting to be input into the following processing programs.

VELOCITY ANALYSES AND DETERMINATION

Preliminary velocities were determined by means of VELANS® (Velocity Analyses) using CDF's in groups of 5 and from previous data in the area. VELAN® locations are chosen at locations dictated by structural configuration. In this program, vertical velocities are automatically determined from cross-correlation of members of each CDP family. After application of digital-start-to-time-break correction, statics and mute, each member of each family is normal moveout corrected for each velocity used in the determination. All possible cross correlations among the members of each family are made for each velocity. The velocities used started at 4000 feet per second and increased in increments of 250 feet per second, to 11,500 feet per second. Every VELAN® was plotted on graph paper by a drum-type, mechanical plotter. This graph illustrated the average correlation for each velocity at each time zone for all of the common depth point families used in the analysis. Curves of average velocity versus reflection time are designated for each of these graphs.

A series of constant velocity stacks were run on the entire Line N-3 due to marginal quality data and sketch VELAN® information.

A family of velocity functions for all three lines was chosen and used to produce NMO/STK displays which includes CDF Stack Monitors for trace 24 and 23 alternately of each 24 trace stacked record. These sections, CDF gathers, constant velocity stacks and VELANS® were utilized in arriving at a final set of composite velocities. The revised velocities were checked by inserting them into second NMO/STKs with stack monitors.

PRE/PROCESSOR

The Pre-Processor outputs both CDF ordered and trace sequential tapes which conform to the SEG "exchange tape" specifications incorporating in reel and trace headers all basic information regarding field parameters. In the pre-processor stage, shotpoint cable geometry is resolved into a set of X and Y coordinates. Thus, all irregularities related to NMO application are solved in this early stage of processing. Initial elevation static corrections to a 4300 foot datum at 6000 ft./sec. were computed from survey and monitor record information and included in the trace headers at this stage.

Output traces were balanced by computing an average RMS from 300 ms. beyond the first arrivals to 10,000 ms. and raising or lowering the trace amplitude to a specified RMS.

NORMAL MOVEOUT APPLICATION

The normal moveout corrections for final sections was computed from the revised velocity functions. The applied time-velocity curve is linearly interpolated for CDP's that are between read-in functions along the line. Information for digital start-to-time-break, statics and distance from energy source is read from the trace headers. A limiting factor of 50 ms. per 100 ms. of trace time was imposed. Muting of first arrival and early refractions was done after NMO, based on standard group interval and distance from the source.

COHERENCY STACK/FILTER

Members of an NMO-corrected common-depth-point family are cross correlated with a model trace generated by one of several optional methods. Each member is shifted to a position corresponding to the maximum crosscorrelation value. Members are then stacked. Crosscorrelation and shifting can be done within time-variant zones. Zones can be deleted by a quality-of-crosscorrelation criterion. Model and/or output trace may be filtered. Program may be utilized as a common-depth-point stack without any time shifting of CDP members. Up to 12000 percent stack is available. The model trace can be refined by successive iterations of the process. A band pass filter of 14-56 Hz. was applied before and after stack. The model was 5 Common Depth Families with a computation zone which encompassed the entire trace length.

Data Enhancement Tests

Deconvolution tests both before and after stacking proved to be unsatisfactory. Since continuity is marginal, it was concluded that, from an interpretive standpoint, the extra legs would be beneficial.

A multichannel filter which enhances coherent events was equally unsatisfactory. It was run with a relatively wide dip acceptance window and

enhanced the large amount of coherent background noise as well as the data. Once the interpretation is made, a more streneous dip discrimination might prove beneficial.

Donald G. Gardner
Quality Control Supervisor

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SEISMIC INTERMEDIATE TAPE FORMAT

TAPE MOTION ←

START OF TAPE	IDENTIFICATION HEADER FILE	E.O.F.	SEISMIC RECORD NUMBER 1	I.R.G.	…	I.R.G.	SEISMIC RECORD NUMBER N	E.O.F.	END OF TAPE

IDENTIFICATION HEADER FILE

CLIENT CARD	I.R.G.	SAMPLE CARD	I.R.G.	FORMAT CARD	I.R.G.	OPTIONAL CARD 1	•••	OPTIONAL CARD L	I.R.G.	PROCESSING HISTORY TITLE CARD	I.R.G.	PROCESS NUMBER 1 CARD	•••	PROCESS NUMBER K CARD

IDENTIFICATION HEADER CARD IMAGE DESCRIPTION

CLIENT CARD

1	3	10	20	27	36	43	80
C	CLIENT		LINE		AREA		{FL / FX}

SAMPLE CARD

1	3	20	25	45	47	70	72	79	80
C	TRACE LENGTH (MS)		SAMPLING INTERVAL		REEL SEQUENCE NUMBER		TYPE		

FORMAT CARD

1	3	24	26	46	52	74	80
C	DATA TRACES RECORDED		UNITS OF DISTANCE		CDF ORDERED RMS		

OPTIONAL CARD

1	3	80
C		

PROCESSING HISTORY TITLE CARD

1	3	80
C	PROCESSING HISTORY	

PROCESSING CODE CARD

1	3	13	22	80
C	PSE4	10/09/69	18.59.02	

CODE 4 SEISMIC TRACE IDENTIFICATION

HALFWORD	
1	FORMAT CODE
2	SAMPLE START INDEX
3–4	FILE NUMBER
5	TRACE NUMBER
6	CDF NUMBER
7	STACK WORD
8	SHOT ELEVATION •
9–10	SHOT X •
11–12	SHOT Y •
13	SHOT STATIC (MS)
14	DETECTOR ELEVATION •
15–16	DETECTOR X • OR AVERAGE CDF X (STACK)
17–18	DETECTOR Y • OR AVERAGE CDF Y (STACK)
19	DETECTOR STATIC (MS)
20	DETECTOR DISTANCE •
21–22	EDIT PARAMETER A
23–24	EDIT PARAMETER B
25	CURVE APPLICATION START TIME (SAMPLES)
26	CURVE APPLICATION STOP TIME (SAMPLES)
27	TIME OF FIRST SAMPLE (MS)
28	MINIMUM SPREAD •
29	SHOTPOINT NUMBER
30	AVERAGE CDF STATIC (MS) ••
31	SHOT STATION NUMBER
32	DETECTOR STATION NUMBER
33	SURFACE ELEVATION ABOVE CDF •
34–36	

•TAPE HEADER WILL GIVE UNITS OF DISTANCE

•• CDF DATUM CORRECTION

Jan. 25, 1974

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